Protection and Security

CS 256/456
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1. Security and Protection
   - Goals:
     - Data confidentiality
     - Data integrity
     - System availability
     - Privacy
     - Malicious intruders
     - Accidental data loss

2. Operating Systems Protection
   - Operating system consists of a collection of objects, hardware or software (e.g., files, printers)
   - Protection problem: ensure that each object is accessed correctly and only by those processes that are allowed to do so
     - a specific type of security problem
   - Domain = set of (object, rights) pairs
     - what is a domain in traditional UNIX?
     - when do process domain switches occur in traditional UNIX?

3. Domain Structure
   - Principle of protection: least privilege
   - Alternatives for domain of protection:
     - Unix: users, groups
     - Multics (1960s): rings of capabilities/protection
How to Track Objects/Rights in Domains?

- View protection as a matrix (protection matrix)
  - Rows represent domains
  - Columns represent objects
  - Access(i, j) is the set of operations that a process executing in Domaini can invoke on Objectj

- Dynamic protection
  - Operations to add, delete access rights

<table>
<thead>
<tr>
<th>Domain</th>
<th>File1</th>
<th>File2</th>
<th>File3</th>
<th>File4</th>
<th>File5</th>
<th>File6</th>
<th>Printer1</th>
<th>Printer2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Read</td>
<td>Read</td>
<td>Read</td>
<td>Write</td>
<td>Write</td>
<td>Write</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Read</td>
<td>Read</td>
<td>Write</td>
<td>Write</td>
<td>Write</td>
<td>Write</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>Read</td>
<td>Write</td>
<td>Write</td>
<td>Write</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Implementation of Protection

- The complete protection matrix consumes too much space and is usually very sparse.
  - Two ways to condense it

  - Each column = Access-control list for one object
    - Defines who can perform what operation.
      - Domain 1 = Read, Write
      - Domain 2 = Read
      - Domain 3 = Read

  - Each Row = Capability List for each domain
    - Define what operations allowed on what objects.
      - Object 1 - Read
      - Object 4 - Read, Write, Execute
      - Object 5 - Read, Write, Delete, Copy

- What does traditional UNIX do?

Access Control Lists

- Use of access control lists to manage file access
  - Revocation of access rights?

Capabilities

- Capability for a domain
  - Abstraction that indicates access rights to objects for the domain

- Compare against ACL
  - May be built-in with handle to objects (more efficient access right checking)
  - Efficient mechanism to pass it around

- Important concern
  - A process should not be able to tamper with its capabilities
Implementing Capabilities

- Kernel-space capability list
  - user programs use handles (e.g., file descriptors) to refer to them

- Tagged architecture
  - memory words containing capabilities are tagged; user programs can only read those words; only kernel programs can change those words
  - the protection system kernel does not need to track capabilities and capabilities can be passed by memory sharing

Cryptographically-protected Capabilities

- Cryptographically-protected capability
  - a random number (called "check") is generated for each file at creation time and maintained in secrecy
  - capability is formed cryptographically

  Function $f()$ is a one-way function such that:
  - it is computationally infeasible to guess what "check" is even when object, rights, and $f(\text{object, rights, check})$ is known.

- Compared with tagged capabilities, cryptographically-protected capability
  - does not require new hardware support
  - can be passed around between distributed machines

Revocation of Access Rights for Capabilities

- Revocation:
  - change the secret check number?

- total: revoking rights to all processes
- selective: revoking rights to a selected group of processes (e.g., all processes belonging to a particular user)
  - Timeout & Reacquisition

Protection in UNIX

- Protection domains: users
- Access matrix for files:
  - a simplified access control list

- Protection commands for files:
  - each user can change protection on files it owns
  - superuser can do everything
Protection in Java

- A Java class can be loaded remotely; therefore can be dangerous.
  - A class is assigned a protection domain when it is loaded by the JVM.
  - The protection domain indicates what operations the class can (and cannot) perform.

- If a library method is invoked that performs a privileged operation, the stack is inspected for access right violation.
- Other techniques:
  - Sandboxing
  - Interpretation

Trusted Systems

- Trusted Computing Base
  - Hardware and software for enforcing security rules.

- If the TCB works according to specification, the system security cannot be compromised.
- A reference monitor-based TCB:

Formal Models of Secure Systems

- Protection commands: operations that can change protection matrix.
- TCB must ensure that protection commands do not move the protection matrix from an authorized state to an unauthorized state.

Covert Channels: Information leaking

- Covert channels
  - Modulating CPU usage
  - Locking/unlocking files

Encapsulated server can still leak to collaborator via covert channels.
### Login Spoofing

- **Login spoofing**
  - A program running by the attacker displays a login screen (like the real one)
  - After a legitimate user types in username and password, it records those, kills itself, and a real login screen is shown
  - The user thinks she typed in a wrong password and tries again, which works

- **Countermeasure?**
  - Start each login session with a non-user-catchable key combination "Ctrl-Alt-Delete"

### Leaking Unnecessary Information

<table>
<thead>
<tr>
<th>Login</th>
<th>Password</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>ken</td>
<td>FooBar</td>
<td>SUCCESSFUL LOGIN</td>
</tr>
<tr>
<td>carol</td>
<td>Idunno</td>
<td>INVALID LOGIN NAME</td>
</tr>
</tbody>
</table>

### User Authentication

- UNIX user passwords are mapped using a one-way function "e()"; and then stored in a globally readable file "/etc/passwd"
  - Bobbie, e(Dog)
  - Tony, e(6%%TaeFF)
  - ...

- **Attack:**
  - used a precomputed common password list

- **Countermeasure?**
  - salt
  - Bobbie, 4238, e(Dog4238)
  - Tony, 2918, e(6%%TaeFF2918)

### Improving Password Security

- **One-time passwords**
  - Challenge-response authentication
- **Authentication using a physical object (e.g., ATM card)**
- **Authentication using biometrics**
The TENEX Password Problem

- Files are accessed with passwords. At each access, the password is checked byte-by-byte and an error is returned as soon as a byte is mismatched.

Buffer Overflow

(a) Situation when main program is running
(b) After program A called
(c) Buffer overflow shown in gray

Countermeasures:
- boundary checks, non-executable stack/data segment, ...

The Morris Worm [1988]

- Three methods of infection
  - rsh from trusted machine
  - Buffer overflow attack in finger
  - Bug in sendmail
- Once a machine was infected, used password cracking for further proliferation
- If a copy of the worm already existed, 1 in 7 exited
  - Downfall since it brought the Internet down

The Security Environment

Security goals:
- Authentication
- Data confidentiality
- Data integrity
- System availability

Threats of intruders or adversaries:
- Identity hijacking
- Exposing data
- Tampering with data
- Denial of service attacks

We focus on OS-related security issues
So far …

• Login and password security
• Cryptography as a tool
• Buffer overflow attack

Security Services

• Privacy (prevent others from obtaining information)
• Authentication (verify the identity of an object owner)
• Data integrity (make sure the data is not altered)

→ Cryptography as a Security Tool

Cryptographic Algorithms

• Encryption/decryption algorithms typically public knowledge
• Key shared between sender and receiver is the difference
  – Secret key — symmetric — both participants share a single key
  – Public key (e.g., RSA)
    • Public key published for all to know
    • Private key that is shared with no one
  – Hash or message digest (e.g., MD5) — no keys
    • Map a potentially large piece of data into a small fixed-length number
    • More efficient to compute than the above techniques

Encryption Algorithm Requirement

• Assumption — only the key is kept secret or you will have to keep re-inventing new encryption algorithms!
• Algorithm must be safe from chosen plain-text attacks (if the attacker knows both plaintext and ciphertext)
  – Make sure none of the structure of plaintext remains
→ Key distribution a central problem in security
### DES – Date Encryption Standard

- Secret key algorithm
- Encrypts 64-bit blocks of plaintext using a 64-bit key
- Three distinct phases
  - Permute (shuffle bits in the block)
  - Perform 16 rounds of an identical operation
  - Perform the inverse of the original permutation
- Decryption – apply the same algorithm, except that the keys are applied in reverse

### Encrypting Large Data

- Cipher block chaining (CBC) – XOR ciphertext for block i with plaintext for block i+1 before running it through DES
- Use initialization vector in lieu of non-existent ciphertext for block 0
- Use Triple-DES to increase security

### RSA (Rivest, Shamir, and Adleman) Algorithm

- Public key for encryption, private key for decryption
- Grounded in number theory
- Encryption/decryption function requires enormous computational power

### Key Selection

- Key length of 512 bits
- Choose two large prime numbers p and q, and multiply them together to get n
- Choose encryption key e such that e and \((p-1)(q-1)\) are relatively prime
- Compute decryption key d such that
- Public key constructed from the pair \(<e,n>\) and private key by the pair \(<d,n>\)
**Authentication: Simple Three-Way Handshake**

- Participants already share a secret key
- Client send encrypted (using client handshake key) random number x along with client id
- Server decrypts and responds with x+1, along with random number y, both encrypted with server handshake key
- Client validates legitimacy of server by checking return value x+1 and returns encrypted y+1
- Server validates legitimacy of client based on response and then sends encrypted session key

**Authentication: Trusted Third Party (e.g., Kerberos)**

- The authentication server S is trusted and shares a secret key with A and B, K_A and K_B respectively
- A identifies A and B to S
- S sends back a two-part message, encoding session key K and a timestamp T, using K_A and K_B
- A decodes first part of message and forwards second part to B along with timestamp encoded using K
- B decodes second part to recover K and T and uses K to decode second part and compare
- B replies with T+1 encoded using K

**PGP – Pretty Good Privacy**

- Provides privacy, authentication, integrity, compression
  - Hash message using MD5
  - Encrypt hash using private RSA key
  - Compress using ZIP
  - Use random key to encrypt message using IDEA (similar to DES)
  - Encrypt random key using receiver’s public key

**Information Leaking Through Side Channels**

- Side channels
  - performance observations
  - program execution signals (e.g., cache usage, memory bus usage)
- Side channel attack on hyper-threading processors [Percival 2005]
  - OpenSSH running DES encryption on one hyper-thread
  - attacker running on the other hyper-thread
  - attacker and OpenSSH share hardware cache, so attacker can monitor its own cache miss pattern to infer the execution of OpenSSH (and its DES encryption key)
Denial-of-Service Attack

- Attacker attempts to consume all available resources at the host so no resources are left to serve legitimate users
  - attacks often come from network and they are distributed
- TCP flooding:
  - attackers establish many bogus TCP connections
  - host allocates buffer space for each connection
  - host memory being exhausted eventually
- Countermeasure?
  - **discard** flooded requests: throw out good and bad ones
  - **trace back** to source of floods
    - attack requests with spoofed identities
    - sources are most likely an innocent, compromised machines
  - **delayed processing/resource allocation**

Virus

- Virus (fragment of code embedded in a legitimate program)
  - program can reproduce itself
    - e.g., when invoked, traverse the file system and attach it to randomly selected executables
  - additionally, do harm
    - steal your data
    - temporarily crash the system
    - permanently damage data or hardware
    - denial of service by using all available system resources
- "Good" virus
  - quickly spreading virus
  - difficult to detect
  - hard to get rid of

Infecting An Executable (Trojan Horses)

- Virus resides in memory; intercepting system calls
- Where in memory to put the virus?
  - known unused memory in OS kernel
  - make the OS believe the memory that virus uses is "legitimately used"
- How to load virus there in the first place?
  - boot sector viruses
  - device driver viruses

Memory Resident Viruses
### How Viruses Spread

- Try to infect programs on
  - networks: exploiting buffer overflow errors in network server daemons
  - floppy drives
- Attach to innocent looking email
  - when it runs, use mailing list to replicate

### Antivirus Techniques

- **Size checkers**
  - keep a record of the size of disk files and scan them periodically for any size changes
  - apply on read-only executables
- **Signature scanning**
  - maintain a database of patterns of common viruses
  - scan disk files for these patterns

### Anti-Antivirus Techniques

- **Integrity checkers**
  - similar to size checkers, but this time we compute a checksum for file and store them somewhere; we periodically check all files to see whether the checksum still matches
- **Behavioral checkers (memory-resident anti-virus program)**
  - intercept system calls and detect suspicious activities: overwriting executables, ...

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(a) A program
(b) Infected program
(c) Compressed infected program
(d) Encrypted virus
(e) Compressed virus with encrypted compression code
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